Computationally efficient removal of inhomogeneities at the cortical surface in MR phase images.

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INTRODUCTION Phase images in MRI are subject to inhomogeneities at the cortical surface due to susceptibility artefacts induced by air/tissue interfaces and inaccurate filtering at foreground/background borders. High pass filtered phase images are derived from the angle of the complex data by either homodyne filtering [1-2], phase unwrapping followed by the subtraction of a low pass filtered version of the phase unwrapped image [3], or a combination of both [4]. Homodyne filtering is ineffective in areas of strong background inhomogeneities, while phase unwrapping methods introduce inhomogeneities due to the inclusion of background voxels in the filtering step. Here, we present a computationally efficient method of removing these inhomogeneities from phase unwrapped images using spatially dependent filters (SDF) and omission of background voxels in filtering calculations.

METHOD MRI data were acquired on a 7T Siemens system with an 8 channel transmit-receive head coil (Neuroscience Research Institute, Incheon, South Korea). Axial T_2*-weighted gradient echo (GRE) images were acquired with TE=21.6ms, TR=750ms, FA=30°, bandwidth=30Hz per pixel, slice thickness=2mm, FOV=256×224 mm^2 and matrix size=1024×896. The spatial resolution was 0.25x0.25x2 mm^3. A total of 17 slices were acquired. The total scan time was 11min 30sec. The phase image was unwrapped using PRELUDE.

The high pass filtered image derived using the traditional filtering method is given by

$$p_{f,TF}(v) = p(v) - F_\sigma * p(v) \tag{1}$$

where $p(v)$ is the unwrapped phase image, v is the voxel, F_σ is the Gaussian filter kernel of standard deviation σ and length and width 2σ, and the symbol * represents the convolution operation.

The SDF method utilises a binary mask identifying foreground voxels, *m(v)*, and a binary mask identifying foreground voxels with phase intensity within one standard deviation of the mean, *t(v)*. A filter size map, *α(v)*, is defined as

$$\alpha(v) = \sigma\left(F_\sigma * t(v)\right)^n \tag{2}$$

where n is a parameter that adjusts the spatially dependent filter size. For each unique value of α, a low pass filtered image is calculated by

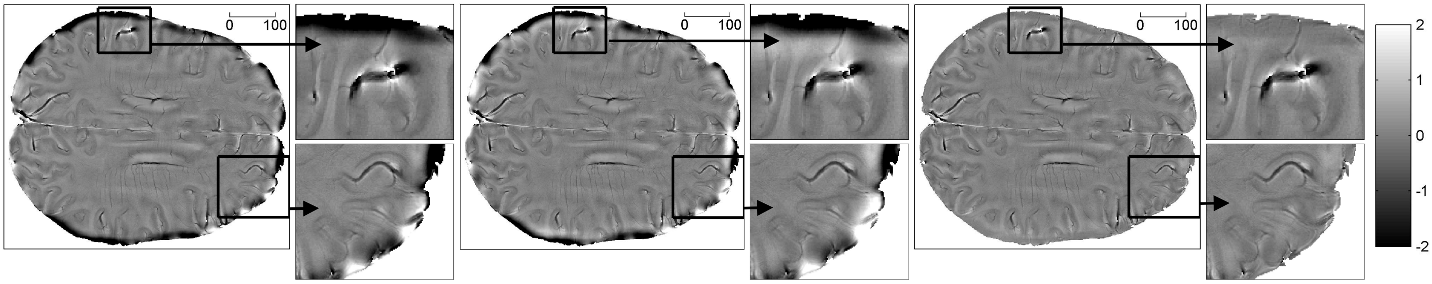
$$p_\alpha(v) = \frac{F_\alpha * \left(p(v)m(v)\right)}{F_\alpha * m(v)} \tag{3}$$

where the multiplication and division operations are element-wise. The final high pass filtered image is given by

$$p_{f,SDF}(v) = p(v) - \sum_{\alpha'} p_{\alpha'}(v) A_{\alpha'}(v), \quad \text{where } A_{\alpha'}(v) = \begin{cases} 1, \alpha(v) = \alpha' \\ 0, \text{otherwise} \end{cases} \tag{4}$$

where, again, the multiplication is element-wise. The filter parameters used were σ =30 and n=3. $\alpha(v)$ values were rounded to two decimal places to reduce the number of iterations of (3) to 89. The traditional filtering and SDF methods were implemented using Matlab.

RESULTS The unwrapped phase image (Fig 1a) demonstrates significant inhomogeneities at the brain edge. The traditional filtering method (Fig 1b) is unsuccessful at removing the inhomogeneities. The SDF method successfully removes these inhomogeneities to reveal hidden cortical structure. The computation time for the SDF method was approximately 2.7 minutes on a Pentium 4 3GHz processor with 1.5GB of RAM.



(a) (b) (c)

Figure 1. (a) Unwrapped phase image, (b) high pass filtered phase image created using the traditional filtering method and (c) high pass filtered phase image created using the SDFS method.

CONCLUSION The SDF method is a computationally fast technique for removing artefacts at the brain surface. The method successfully removes inhomogeneities in the cortical areas and reveals details in the underlying structure.

REFERENCES [1] Noll et al, *IEEE TMI*. 1991, 10:154-163. [2] Wang et al, *JMRI*. 2000, 12:661-670. [3] Chavez et al, *IEEE TMI*. 2002, 21:966-977. [4] Rauscher et al, *Mag. Res. Imag*. 2008, 26:1145-1151.